NASA/TM—2000-210053

Steady State Vacuum Ultraviolet Exposure Facility With Automated Calibration Capability

Thomas J. Stueber and Edward A. Sechkar
Dynacs Engineering Company, Inc., Brook Park, Ohio

Joyce A. Dever and Bruce A. Banks
Glenn Research Center, Cleveland, Ohio

May 2000

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Prepared for the
8th International Symposium on Materials in a Space Environment and 5th International Conference on Protection of Materials and Structures from the LEO Space Environment
sponsored by the Centre National D'Etudes Spatiales
Arcachen, France, June 5–9, 2000

National Aeronautics and
Space Administration

Glenn Research Center

May 2000

Available from

NASA Center for Aerospace Information
7121 Standard Drive
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National Technical Information Service
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Springfield, VA 22100
Price Code: A03

STEADY STATE VACUUM ULTRAVIOLET EXPOSURE FACILITY WITH AUTOMATED CALIBRATION CAPABILITY

Thomas J. Stueber and Edward A. Sechkar
Dynacs Engineering Company, Inc.
2001 Aerospace Parkway
Brook Park, Ohio, 44142

Joyce A. Dever and Bruce A. Banks
National Aeronautics and Space Administration
Glenn Research Center
21000 Brookpark Road
Cleveland, Ohio, 44135

ABSTRACT *- NASA Glenn Research Center at Lewis Field designed and developed a steady state vacuum ultraviolet automated (SSVUVa) facility with in situ VUV intensity calibration capability. The automated feature enables a constant accelerated VUV radiation exposure over long periods of testing without breaking vacuum. This test facility is designed to simultaneously accommodate four isolated radiation exposure tests within the SSVUVa vacuum chamber. Computer-control of the facility for long term continuous operation also provides control and recording of thermocouple temperatures, periodic recording of VUV lamp intensity, and monitoring of vacuum facility status. This paper discusses the design and capabilities of the SSVUVa facility.*

1 - INTRODUCTION

Polymers selected for space missions are required to maintain mechanical and optical integrity for the duration of the planned mission. Concerns over a candidate polymer's environmental durability warrant preliminary ground-based testing involving exposure to simulated environmental conditions. One environmental condition targeted as a potential threat to polymer film material is vacuum ultraviolet (VUV) radiation (wavelengths below 200 nm) from the sun. As a result of long term solar exposure, absorption of the short wavelength VUV radiation may lead to bulk or surface material effects that compromise the optical and mechanical properties of polymer films. To investigate this vulnerability, a significant portion of the expected accumulative equivalent solar radiation exposure for a mission's lifetime should be simulated in a ground-based test. For timely analysis, these ground-based tests may involve accelerated radiation exposures of approximately 3 to 5 times the sun's intensity. Therefore, a typical ground-based test exposure period will span approximately 3 months for each simulated solar exposure year. To accomplish this VUV durability test effectively and efficiently, a facility capable of unattended around-the-clock operation is needed. To this end, NASA Glenn Research Center at Lewis Field designed and developed a steady state vacuum ultraviolet automated (SSVUVa) facility with in situ VUV intensity calibration capability. The automated feature makes a constant VUV exposure rate available to a target throughout the duration of a test without breaking vacuum. The test samples, typically located in the same horizontal plane as the VUV target, can also be thermally controlled to maintain an expected mission's operating temperature. The SSVUVa facility uses deuterium lamps to generate VUV radiation in the wavelength range of 115 to 200 nm. VUV radiation intensity at the target is periodically assessed with the use of calibrated cesium-iodide (CsI) phototubes. The CsI is calibrated to a National Institute of Standards and Technology (NIST) supplied VUV source. Based on the results of these periodic CsI measurements, the VUV radiation intensity may be automatically adjusted. The VUV radiation intensity at the target is adjusted by changing the distance between the deuterium lamps and the target. The SSVUVa test facility is designed to simultaneously accommodate four isolated exposure tests, each with unique requirements. Computer-control of the facility for 24-hour operation provides control of one and recording two thermocouple temperatures, periodic control and recording of the target's VUV radiation exposure intensity, and monitoring the status of the vacuum facility. The vacuum facility can maintain a pressure of 5×10^{-6} Torr.

2 - SSVUVa SYSTEM COMPONENTS

The block diagram of Fig. 1 displays the components that make up the SSVUVa facility used for VUV radiation exposure durability testing. VUV radiation exposure is conducted within a cylindrical (17.75" inside diameter x 30" height) stainless steel vacuum chamber with two 14" (outside diameter) load lock doors, each with a viewport. The vacuum chamber uses a helium cryogenic pump to maintain a 5×10^{-6} Torr vacuum and is partitioned into four separate exposure regions. The four exposure regions are separated by water-cooled Cu walls to minimize thermal and VUV radiation cross interactions between regions. The Cu plates are oriented within the chamber such that each door provides user access to two exposure regions. The typical exposure region j (j = 1, 2, 3, or 4), shown in Fig. 2, has a motor controlled stage ($Stage_j$), two quartz-tungsten-halogen (QTH_j) lamps, two T-type thermocouples ($Th1_j$ and $Th2_j$), a 30 watt deuterium

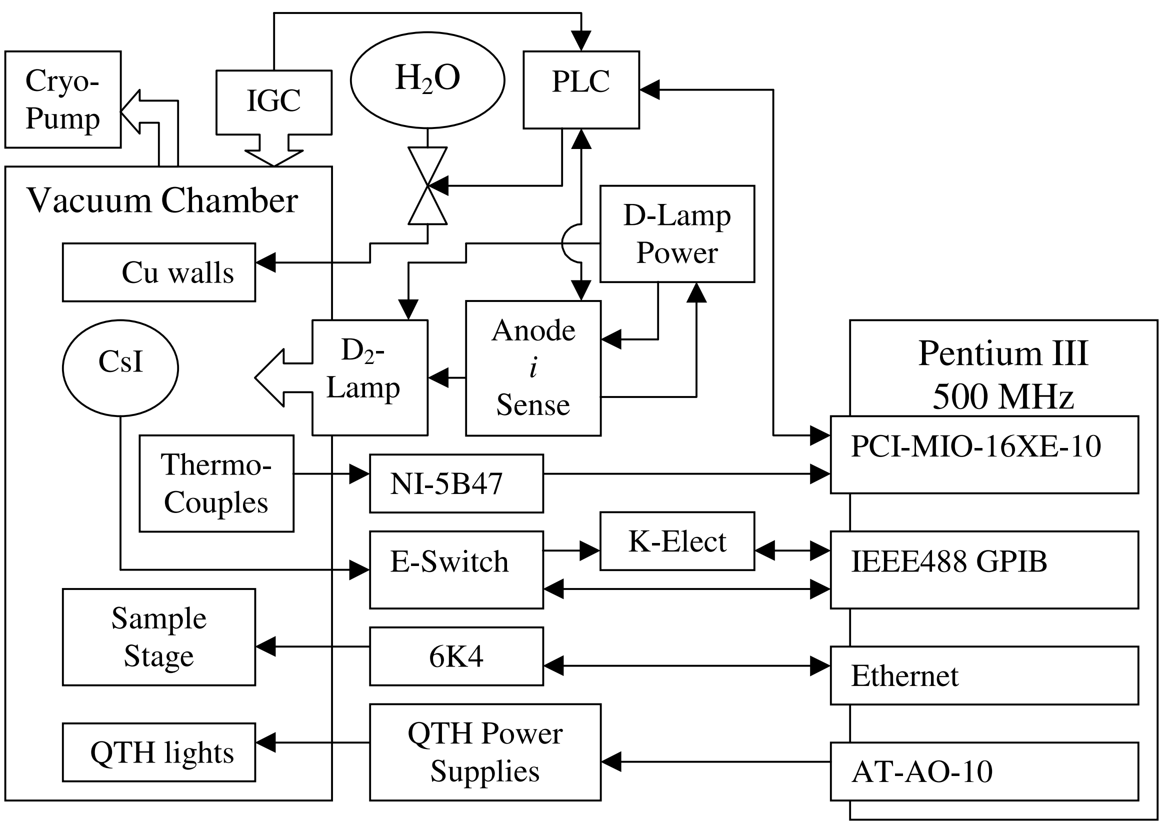

Fig. 1: Block Diagram of SSVUVa Components.

lamp (D_2-lamp$_j$) with a magnesium fluoride window, and a cesium iodide (CsI_j) phototube with a magnesium fluoride window. The target is δ_j above the top surface of Stage$_j$, δ_j is typically the thickness of the test sample and is operator defined. The samples of region j are placed on Stage$_j$. Stage$_j$ is mounted on a motor controlled lead screw that will raise or lower to increase or decrease their VUV radiation intensity at the target of the j^{th} exposure region. The QTH_j lamps apply controlled heat through infrared radiation with the service of a closed loop proportional, integrating, and differentiating (PID) controller. The PID controller uses only one of the two thermocouples available in each exposure region for closed loop temperature feedback. However both thermocouples are available for operator feedback. The bodies of the Hamamatsu model L879-01 D_2-lamps are located outside the vacuum chamber with their end-tubes pushed through vacuum feedthroughs--consisting of an o-ring compression fitting--and pointed at the target. Each D_2-lamp$_j$ feedthrough is located in the chamber's top flange above the j^{th} exposure region and provides a 2.5" diameter exposure area in the horizontal plane of the target. A gate valve is positioned between the main chamber and each of the D_2-lamps' feedthroughs to enable the maintenance and replacement of D_2-lamp$_j$ without breaking main chamber vacuum and disturbing the tests being conducted in the other exposure regions. The D_2-lamps are guaranteed for 2000 hours of continuous service; however, the sacrificial magnesium fluoride windows will need to be cleaned or replaced after approximately 150 hours of operation due to transmittance degradation from VUV-fixed contamination buildup [Tribble 95]. The sacrificial magnesium fluoride window can be easily cleaned or replaced by the operator, without breaking chamber vacuum by sectioning off D_2-lamp$_j$ with the its gate valve. Similarly, a failed D_2-lamp$_j$ can be replaced. The Hamamatsu Model R1187 CsI_j phototube is employed to make periodic measurements of the D_2-lamp$_j$'s VUV radiation intensity at the target. The motor controlled lead screw for Stage$_j$ is also used to position the CsI_j detector.

The SSVUVa facility employs a Pentium III, 500 MHz computer with Microsoft's Windows 98 operating system and is used to run the "CppSSVUV.exe" computer program. The program is

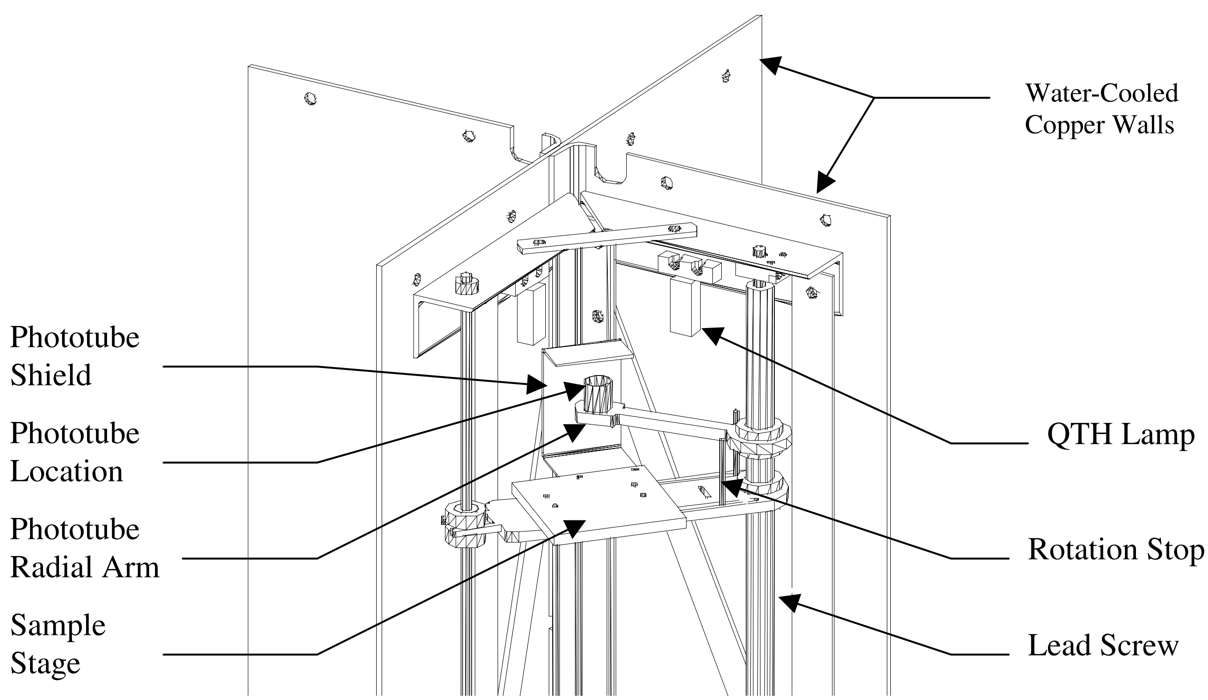

Fig. 2 Typical Physical Layout of an Exposure Region

written in Visual C++ and is designed to provide automated control of all four VUV exposure regions. The following resources are available to the computer program: a PCI IEEE-488 general purpose interface board (GPIB), a Keithley model 6514 electrometer system (K-Elect), a Keithley model 7001 switch system (E-Switch), a National Instruments (NI) AT-AO-10 computer card, a NI PCI-MIO-16XE-10 computer card, an Ethernet port, a General Electric/Fanuc Series One Plus programmable logic controller (PLC), and four D_2-lamp anode current sense circuits. The GPIB board is used to facilitate communication between the computer and the two Keithley instruments. The K-Elect is employed to read the short circuit currents from the CsI_j. The E-Switch enables electronic selection of a CsI_j detector to provide a signal for the K-Elect. The AT-AO-10 is a digital to analog converter board used to control the four QTH_j lamps' power supplies. The PCI-MIO-16XE-10 board is an analog to digital converter and is employed to monitor the thermocouples. The Ethernet port interfaces with a Parker 6K4 motion controller. The 6K4 controls four single stepper motor power supplies. The j^{th} stepper motor power supply controls $Stage_j$'s stepper motor. The PLC is used to turn on, off, and monitor each D_2-$lamp_j$ and turn on and off the cooling water supply valve. The D_2-$lamp_j$'s anode current sense circuit is used by the PLC to detect the presence of current in the D_2-$lamp_j$'s anode. The PLC is also employed to monitor the normally open relay gate of a Varian SenTorr ionization gauge controller's (IGC) pressure set point. A loss in chamber pressure will de-energize this gate. Electronic communication between the computer and the PLC is conducted with the digital ports of the computer's PCI-MIO-16XE-10 board.

3 - SSVUVa SYSTEM OPERATION

3.1 - VUV Radiation Calibration

Each CsI_j detector is used to make absolute measurements of VUV radiation intensity (within the range of 115 to 200 nm) from D_2-$lamp_j$ at the target; therefore, they are calibrated with respect to a NIST calibrated D_2-lamp (NIST lamp) in vacuum before and after a test exposure period. Calibration is conducted by installing the NIST lamp into the location of D_2-$lamp_j$. The CsI_j detector is then positioned at the target, 25.4 cm downstream of the NIST lamp's end tube, and the short circuit current from CsI_j is measured with the K-Elect (E-Switch configured for K-Elect to read CsI_j). A calibration factor ($C_{f,j}$) in units of $W/cm^2/A$ is determined from the ratio of the given NIST lamp intensity (W/cm^2) and the measured CsI_j short circuit current (Amps). The calibration exercise is also conducted post test to account for a degrading CsI_j detector throughout the duration of the test exposure period. Upon completion of the calibration exercise, D_2-$lamp_j$ is reinstalled into its position.

3.2 - SSVUVa System Thermal Management

The water-cooled Cu walls separating the exposure regions will prevent thermal cross interactions between adjacent exposure regions. Therefore, the simple single-input-single-output (SISO) PID controller of equation 3.1 is capable of providing adequate temperature control. The closed loop temperature feedback ($y_j(t)$) is provided with a T-type thermocouple. The thermocouple sensors are connected to a NI 5B backplane with T-type linearized thermocouple input (cold junction compensation) analog signal conditioning modules (NI-5B47). The NI-5B47 converts a 0 to 200°C T-type thermocouple signal to a 0 to 5V analog signal readable by the PCI-MIO-16XE-10 board's

$$u_j(t) = k_{j,c}(U_{j,c} - y_j(t)) + \frac{k_{j,c}}{T_{j,i}}\int_0^t (U_{j,c} - y_j(t))dt - k_{j,c}T_{j,d}\frac{de_j}{dt} \quad 3.1$$

where:

j	Exposure region number (j = 1, 2, 3, or 4)	$U_{j,c}$	Desired temperature (temperature controller set point)
$k_{j,c}$	Proportional gain constant	$u_j(t)$	PID control signal
$y_j(t)$	Measured temperature	$T_{j,i}$	Integration gain constant
$T_{j,d}$	Derivative gain constant	e_j	Error = $U_{j,c} - y_j(t)$

The parameters $k_{j,c}$, $T_{j,i}$, and $T_{j,d}$ are constant and established prior to test initiation.

analog input ports. Each thermocouple has a NI-5B47 module. Since the controller is SISO, only one thermocouple per exposure region is used for temperature control. The other thermocouple installed in each exposure region is for operator's visual feedback. The thermocouples are also used as interlocks to prevent over-temperature conditions.

3.3 - Test Operation

Prior to test initiation, the operator defines the desired number of equivalent sun hours ($ESH_{d,j}$) the samples are to experience, the acceptable accelerated VUV radiation sun intensity extremes, the temperature controller's set point, and the thermal interlock values. Throughout the test period, the temperature control signal is calculated and applied to the QTH_j's power supply every two seconds. Periodically, D_2-lamp$_j$'s equivalent sun intensity (ES_j) is evaluated. The period between ES_j analysis is operator defined. To obtain ES_j, CsI_j is automatically moved into D_2-lamp$_j$'s beam, with the detector's active surface in the same plane as the target (test sample's surface). The CsI_j detector, being mounted on a radial arm that extends from the same lead screw that moves Stage$_j$, is lowered and rotated into position from a shielded location by lowering Stage$_j$. CsI_j is normally stowed under a shield to minimize degradation of CsI_j due to VUV exposure and to prevent sample shadowing. CsI_j's rotational range of movement is mechanically limited and this limit is reached within one full revolution of the lead screw. A typical lowering distance for CsI_j requires several revolutions of the lead screw (lead screw has a 0.3175 cm pitch). D-lamp$_j$'s intensity (W/cm^2) is the product of $C_{f,j}$ (W/cm^2/A) and the measured short circuit current of the CsI_j detector (A). ES_j is the ratio of D_2-lamp$_j$'s intensity and the intensity of the sun. The sun's solar intensity is defined by the operator prior to test initiation and has a default value of 1.0378×10^{-5} W/cm^2 (air mass zero, 115-200 nm). The distance between D_2-lamp$_j$ and the target will be automatically adjusted if ES_j is outside the operator-defined limits. CsI_j is returned to its stowed location after each periodic ES_j measurement. The sample's $ESHs_j$ of exposure is calculated by integrating the ES_j curve with respect to time. This value is refreshed after each periodic ES_j measurement. The test exposure period is complete when ESH_j meets or exceeds $ESH_{d,j}$.

3.4 - Reports

The following two on-line plots are available to the operator during the test exposure period: all thermocouple temperature measurements with respect to time and ES_j measurements from each of the four exposure regions. The viewable time span ($T_{s,j}$) for the online plot containing temperature measurements is pretest defined by the operator along with the maximum number of points to be displayed on the online plot ($N_{T,j}$). Therefore, the temperature plot is updated every $T_{s,j}/N_{T,j}$ seconds. Furthermore, if desired by the operator, the temperature values can also be saved into a data file to facilitate future hardcopy reports. The ES_j plot is designed such that the data points plotted span the entire plot. Therefore, each addition to the ES_j plots warrants plot re-sketching. After plotting the 100^{th} data point, the plot is re-sketched with only the latter 50 data points spanning the entire plot. This plot can also be saved into a data file. The minimum and maximum limits of both plots are automatically adjusted to maximize the plot's display on the chart. The operator, without test interruption, can easily download the data files containing temperature and ES_j information to a Zip disk. This feature makes available SSVUV exposure data, both temperature history and ES_j data, for reports prior to test completion.

3.5 - On-line Test Interlocks

The following four scenarios will prematurely shut down the j^{th} exposure test:

1. adjustment of the distance between D_2-lamp$_j$ and the target in region j is ineffective towards getting the ES_j value within defined tolerance,
2. temperature measured from $Th1_j$ or $Th2_j$ exceeds pretest defined maximum limits,
3. the reading from the thermocouple selected for PID controller feedback is outside a pretest defined tolerance band, and
4. D_2-lamp$_j$'s anode current sense circuit stops detecting current.

A loss in vacuum pressure will shut down all testing and shut off the cooling water supply.

4 - SUMMARY

The SSVUVa facility is capable of uninterrupted, safe, extended, and accelerated VUV radiation exposure on samples located in the planes of the four target locations--2.5 inch exposure beam diameter. The samples can be temperature controlled to replicate expected mission thermal conditions. The uninterrupted capability of this facility, due to the automatic VUV intensity adjustment capability, will minimize operator interactions with the ongoing tests. The sacrificial magnesium fluoride window can be easily cleaned or replaced by the operator, without breaking chamber vacuum by sectioning off the deuterium lamp with the lamp's gate valve. Similarly, a failed deuterium lamp can be replaced without breaking chamber vacuum. Online generated plots describing measurement history of all thermocouple readings and equivalent sun intensities are available for onscreen viewing and downloading to disk to facilitate report generation. Interlocks implemented involving thermal constraints, VUV radiation intensity tolerance, and vacuum monitoring ensure safe sample exposure conditions and facility operation.

REFERENCES

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2000	Technical Memorandum

4. TITLE AND SUBTITLE

Steady State Vacuum Ultraviolet Exposure Facility With Automated Calibration Capability

5. FUNDING NUMBERS

WU–632–6A–1E–00

6. AUTHOR(S)

Thomas J. Stueber, Edward A. Sechkar, Joyce A. Dever, and Bruce A. Banks

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–12254

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—2000-210053

11. SUPPLEMENTARY NOTES

Prepared for the 8th International Symposium on Materials in a Space Environment and 5th International Conference on Protection of Materials and Structures from the LEO Space Environment sponsored by the Centre National D'Etudes Spatiales, Arcachen, France, June 5–9, 2000. Thomas J. Stueber and Edward A. Sechkar, Dynacs Engineering Company, Inc., 2001 Aerospace Parkway, Brook Park, Ohio 44142; Joyce A. Dever and Bruce A. Banks, NASA Glenn Research Center. Responsible person, Joyce A. Dever, organization code 5480, (216) 433–6294.

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Unclassified - Unlimited
Subject Category: 33 Distribution: Nonstandard

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13. ABSTRACT ***(Maximum 200 words)***

NASA Glenn Research Center at Lewis Field designed and developed a steady state vacuum ultraviolet automated (SSVUVa) facility with in situ VUV intensity calibration capability. The automated feature enables a constant accelerated VUV radiation exposure over long periods of testing without breaking vacuum. This test facility is designed to simultaneously accommodate four isolated radiation exposure tests within the SSVUVa vacuum chamber. Computer-control of the facility for long term continuous operation also provides control and recording of thermocouple temperatures, periodic recording of VUV lamp intensity, and monitoring of vacuum facility status. This paper discusses the design and capabilities of the SSVUVa facility.

14. SUBJECT TERMS

Vacuum; Ultraviolet; Radiation; Exposure; Facility

15. NUMBER OF PAGES

12

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	